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HAZARDS OF FIRE AND EXPLOSION OF ANESTHETIC AGENTS

III. In the Presence of Diathermy

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THIS report, the third in a series on the fire and explosion hazard in modern anesthesia, is best viewed as a logical development of our previous reports. It is especially related to the paper on cautery ignition (3), which we recommend for study before reading this report.

The application of high frequency electrical currents to surgery is widespread and increasing; it is practically indispensable in some phases of modern surgery, especially neurological and genitourinary surgery. Therefore, anesthetists must accept the presence of electrosurgical apparatus in the operating room and must adapt their methods to this hazard.

Paralleling the increased use of electrical instruments in the presence of anesthetic agents and equipment is the decreased use of open ether and chloroform volatilized with air, and the greater utilization of semiclosed and completely closed methods of administration of ether, ethylene, and cyclopropane, with high concentrations of nitrous oxide or oxygen, or both. While these changes have been of great value in diminishing intraoperative and postoperative morbidity, they have, unfortunately, augmented the likelihood of serious injury to the patient and the surgical team exposed to an anesthetic combustion. It is more important than ever before to prevent anesthetic ignition, especially the entirely preventable types associated with electrical apparatus.

A marked discrepancy and a lack of unanimity in anesthetic practices exist with regard to these dangers. Even in hospitals with otherwise progressive departments of anesthesiology, we have found unsafe techniques in use. Many have adopted inadequate compromises as a result of incomplete understanding of the details of the hazard, e.g., barring ethylene and cyclopropane but allowing ether (17), or forbidding combustible inhalation anesthetics in head and neck electrosurgery but permitting them in surgical diathermy employed at more remote points of the body or extremities (5).

It is high time that there be established a universally accepted standard of safe practice of anesthesia with diathermy. We believe that our studies have secured sufficient information to make this possible, and more, to make it convincing.

ELECTRICAL DATA

The basic information about combustible anesthetics has been presented in detail in foregoing reports (3, 4). All that is necessary, we believe, to secure understanding and agreement with our opinions on this type of electrical hazard is a presentation of the electrical aspects of high frequency apparatus as they are related to the possibility of igniting a combustible inhalation anesthetic mixture.

The heat necessary for ignition—182 to 517 degrees C. (3) may be considered present whenever a visible or audible spark is produced. For practical purposes, this is a necessary and safe rule even though it might be shown that there are degrees of sparking which cannot ignite anesthetic mixtures (we do not know of any such proof). When the surgical diathermy is employed, sparking or arcing may appear in five zones: (1) at the active electrode during fulguration, coagulation, or cutting; (2) within the cabinet of the apparatus if the machine has a spark-gap or defective insulation; (3) at the foot or hand switch controlling the make and break of the circuit; (4) at the wall plug socket during the make or break of the connection; (5) *this is the one source of sparking usually overlooked*—at many scattered and unpredictable points where a high frequency current or induced current jumps an air gap formed between the patient (charged by the high frequency electricity coursing between the two electrodes) and a grounded conductor or any conductor of sufficient electrical capacity to accept a charge. Such a conductor may be a nearby grounded or ungrounded machine or person.

We must consider each of the five zones in greater detail with regard to explosion protection from the sparks arising in each zone.

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1. The active electrode always produces a spark or arc whether the high frequency current is adjusted for fulguration and coagulation (which are visibly associated with arcing) or for cutting. This knife-like action is performed, not by a hot electrode, but by an arc which forms ahead of the electrode and which separates the tissues by volatilizing them (2). The danger arising from the arcing active electrode is as obvious and as localized as that of the hot-tipped actual cautery. All the rules suggested in our earlier report (3) on the cautery may be applied here. We refer the reader to this paper for details.

2. The sparks in the cabinet of the apparatus may be caused by the multiple spark-gap frequently used to produce the high frequency oscillating current. This source of sparking is absent in the type of equipment which substitutes radio vacuum tubes for the spark-gap mechanism. Another source of sparks may arise from faulty or worn insulation or loose contacts. All of these internal machine sparks may be rendered innocuous by following the same precautions as have been described for the active electrode or actual cautery. Another method of protection that has been employed is the placing of the machine outside of the operating room and using very long lead-in wires to the electrodes.

3. The sparking at the foot or hand switch is an obvious hazard easily removed by enclosing it in a bag through which it may be operated, similar to the suggestion made for the fluoroscopic foot switch.

4. The plug-socket hazard at the wall connection may be avoided by inserting the plug before the start of anesthesia and removing it only after the anesthesia has ended and the room well ventilated. To prevent accidental disruption of the connection, one should use a locking type of wall socket (21). Of course, if the socket is located outside of the operating room, the above precautions are unnecessary.

5. The scattered and unpredictable type of sparking mentioned before in zone 5 cannot be surely and safely prevented, as the following consideration explains. Arcs may be produced in the presence of high frequency generators under conditions that would be absolutely safe from any other form of electrical spark. There are two reasons for this: (a) Arcs may be drawn from a high frequency conductor by a grounded conductor or by any conductor of relatively high capacity, e.g., a human body, even if it is perfectly insulated. In the case of an insulated body, it is continually charged and discharged by electromagnetic induction and if the distance is small, this electromagnetic stress will cause ionization of the air in between to the extent of forming a continuous arc. (b) An otherwise well insulated conductor may acquire an induced high frequency voltage by being near a high frequency conductor. Arcs may then be drawn from it very easily as described in (a). Many substances which are poor conductors or even good insulators to direct current or low frequency alternating current are good conductors of high frequency electricity. All of these special characteristics observed in using high frequency increase in proportion to the frequency; and the frequencies employed in surgical diathermy are very high.

This information shows how difficult it is to limit the path of high frequency electricity and the possible points of arcing. Even with the inactive electrode on the sacrum and the active electrode at the urethra, the currents are traversing all parts of the patient and are not entirely confined to a narrow path lying between the electrodes. "A current diffuses itself more or less throughout the body" (11). This devious route is followed partly because of the varying electrical resistances of the structures in its path. No matter how far the electrodes may be from the mask, the hazard of arcing in or near the inhalation system is a constant threat.

The prevention of this diffuse type of sparking is possible theoretically by connecting the patient to all objects and persons likely to approach him closely. To offset the increased hazard of electric shock introduced by this greatly increased circuit and capacity, it would be necessary to add a high resistance barrier between each person and any likely grounding contact. It should be apparent how difficult this would be. Much more so than the Horton system (9) of intercoupling described for the prevention of electrostatic sparking. For, in addition to the group connected by the Horton intercoupler, (operating table, patient, anesthetist, and anesthetic apparatus) it would be necessary to include in the circuit all of the surgical teams and instruments which might draw a spark from the electrically connected patient and group in the immediate vicinity of the anesthetic inhalation system.

It should be evident why we consider the use of a combustible inhalation anesthetic mixture as entirely unsafe in the presence of electrosurgery anywhere on the patient. Even with precautions theoretically possible but never applied and highly impracticable, the practice is not as safe, more cumbersome, and less practicable than the use of noncombustible anesthetic methods and techniques. The progress of anesthesiology in the direction of regional blocks, spinal anesthesia, rectal basal narcosis, and intravenous barbiturate anesthesia now makes it safe and feasible for a trained anesthetist to administer a noncombustible anesthetic whenever high frequency currents must be employed.

Our personal experience is worth citing as typical of the necessary and practicable adjustments in anesthetic methods safe for use in the presence of x-ray and diathermy apparatus. In our early years, we were fortunate in our ignorance to have used, without mishap, ether-oxygen-nitrous oxide and cyclopropane-oxygen for fluoroscopic surgery and surgical diathermy in various parts of the body, ranging from the breast to the cervix. With further education and experience, we have learned to discard these dangerous practices and to substitute noncombustible methods without serious difficulty. An increased use of spinal and other regional blocks, intravenous barbiturates and rectal basal narcotics combined with nitrous oxide-oxygen or regional blocks has enabled us to supply noncombustible anesthesia whenever the surgeon has desired to use the x-ray or diathermy. And at no time were we ever doubtful of the safe control of the depth of the anesthesia. Our most common occasions for changing a combustible inhalation anesthesia to a noncombustible technique have occurred in radical breast and neurological surgery. In both, we have been well pleased by the supplemental use of minimal amounts of intravenous barbiturates injected into the tubing of the infusion usually started with radical breast and neurological surgery. Simultaneously, the combustible agent is removed from the apparatus and "washed out" of the patient. The inhalation apparatus is used to supply nitrous oxide-oxygen with relatively large amounts of oxygen (20 to 25 per cent) and to provide an accurate indicator of the respiratory excursions. We have found this combination of minimum doses of pentothal sodium with optimum oxygen-nitrous oxide the answer to most of our problems of supplying noncombustible anesthesia in the presence of diathermy, when spinal or regional block was impracticable.

CLINICAL DATA

We have found published warnings (7, 8, 16, 18, 19, 22) against the use of diathermy apparatus with inflammable agents as far back as 1924. Through the 16 years, it has been repeated again and again. Yet explosions and deaths have been caused by the practice even up to the present; and the hazard is being repeatedly tempted in very many hospitals, even by some of the largest. We believe that the reasons for this continued violation of safe practice are four; one or more of these accounting for the persistence of the dangerous combination in different institutions: (1) Ignorance—of the physics and chemistry of the subject and therefore of the reality of the hazard; (2) indifference—to the hazard because of past "blind" good luck and because of unawareness of the catastrophes experienced by others; (3) inflexibility—of available methods of anesthesia because of lack of versatility and training in the anesthetist, forcing the use of combustible anesthetics in hazardous circumstances; (4) conflict—of opinion among surgeons, anesthetists, and diathermy manufacturers, fostered by the lack of an official and unequivocal censure of the unsafe practice.

In the literature and in our discussions with many anesthetists and surgeons, we have noted an almost universal disregard or oversight of the "diffuse sparking" tendency of high frequency currents, a fact long known to physicists. We have found only two statements alluding to this feature, but both without explanation. Size (20) has stated "at the present time there does not seem to be any certain way of guarding against miscellaneous sparking from this procedure," i.e., diathermy. The Minister of Health for England and Wales, in a memorandum (14) on the use of electrical apparatus in the presence of an inflammable anesthetic, pointed out that the patient, under an electrical potential while in a surgical diathermy circuit, may allow a spark to jump from himself to the operating table or anesthetic apparatus.

The elimination of the first three of the reasons stated above, for the persistence of the unsafe practice of mixing diathermy with inflammable anesthesia, is entirely dependent on the universal elevation of the standards of education and supervision of anesthesia and anesthetists. Fortunately, this is rapidly, but not rapidly enough, becoming a reality.

Most authorities condemn the practice under discussion, but we have found several writers who have permitted the loophole to remain, through which the erring anesthetist may escape condemnation. These writers, usually on very inadequate grounds, have indicated that ether inhalation is permissible with diathermy. For example, Mock stated "The anesthetic of choice in these cases of goiter is 0.5 per cent procaine hydrochloride used locally. With this anesthetic no precaution need be taken on account of the electrical current. Nitrous oxide may be used without fear of an explosion, and ether can be used. In the lat-

ter 2 cases, a wet flannel roll is placed just below the lower edge of the mask and further protection against the fumes of the ether reaching the electric spark is provided by a rubber apron placed over the anesthetic frame and held tightly by clips against the skin of the cheeks and chin. If a general anesthetic is necessary, rectal ether anesthesia, as in one of my cases, may be used. In all but one of the 15 cases in this series, local anesthesia was used." It is apparent that this author was recommending ether inhalation with electrosurgery of the thyroid gland without ever having used it.

Even the discoverer of the clinical usefulness of ethylene for anesthesia has committed the error of advising a combustible inhalation anesthetic with surgical diathermy. In 1924, Luckhardt and Kretschmer reported their use of ethylene anesthesia in 13 cases of fulguration of the urinary bladder and 1 case of carcinoma that received diathermy. In this article, they stressed the fire and explosion hazard of flame, cautery, and electric sparks. Then they described the careful placing of the spark-gap apparatus at a distance from the patient, with the machine cover kept shut and the lead wires to the electrodes drawn through holes drilled through the walls of the cover. Yet they failed to recognize the danger of the sparking active electrode and the greater threat of "diffuse sparking" from any part of the patient. No explosion occurred even though this was in the days of only semi-open administration of ethylene. This is an excellent example of the fact that failure to cause an explosion by violation of the rules of explosion prevention cannot be used as evidence of the harmlessness of the bad practice. An explosion is the result of the coincidence of many predisposing factors, of which the absence of any one may prevent the accident favored by the many other favorable influences.

We have been surprised to find Guedel allowing "Ethylene, properly managed, may be used in electric fulguration within the bladder if the air bubble above the water is held to minimal size and the fulguration spark is not permitted to reach the bubble" (6).

Kovacs (12), in his authoritative textbook on electrotherapy, has contributed to the indecisiveness of the warning against using diathermy with ether by describing its use in one paragraph, but, in the next, saying "since, however, there have been occasional serious accidents resulting from ignition and explosion of ether vapor it is better to avoid its use when possible."

Kelly and Ward, in their textbook entitled *Electrosurgery*, repeatedly advised the use of the hazardous technique of interrupted open ether anesthesia for oral and other types of surgical diathermy, stating that the risk is slight with proper precautions, i.e., the patient exhales a few times and all ether-soaked materials are removed. While this was their most common method of general anesthesia, probably because of a lack of trained anesthetists, they admitted that "rectal anesthesia administered by a trained anesthetist is the method par excellence."

Many manufacturers, in the commercial literature accompanying their diathermy apparatus (17), have warned against the use of ethylene but advised that ether might be used with only the precautions of an ether screen and wet towels. One of the leading manufacturers so poorly understood the ignition possibilities of diathermy, that he considered the sparking hazard present only in the spark-gap type of machine and absent in the vacuum tube models.

The precautionary steps necessary to allow the change-over from a combustible anesthetic to a noncombustible one for use with diathermy are the same as are those which have been advised and described for cautery surgery (3) about the head after a combustible inhalation agent has been used.

There are three other varieties of hazard of special interest to the anesthetist when the diathermy is operated in the surgery: (1) The active electrode can ignite an inflammable cleansing or antiseptic fluid painted on the surgical field as it did in 3 cases. In this respect, the cautery and diathermy present the same problems. The field and drapes prepared with an inflammable cleanser or antiseptic should be thoroughly dry before the active electrode is applied, or better yet, a noncombustible fluid should be used. (2) There is a type of accident peculiar to bladder fulguration during which hydrogen may be liberated by the decomposition of the irrigating water within the bladder. The hydrogen rises to the dome of the bladder, mixes with the air bubble, and is subject to explosion whether or not an inflammable anesthetic agent is in use (6). (3) The last type of danger is that of electrical short-circuiting with the resulting effects of electrical shock and sparking. These are possibilities which are ever present with electrical apparatus of any type receiving its source of power from a house current (110–220 volts). The main line of current may reach the operator or patient or by stander accidentally or intentionally in circuit with a part of the apparatus which has become "live" because of a break in the insulation within the machine or a defect in a condenser. This allows a leak of the main 110 to 220 volt current to a metal part that is usually insulated or to the secondary circuit which normally carries only a very small amperage. If "grounding" is in use, the electrical shock and the short-circuit spark are increased. The presence of a megohm resistance, as in the Horton intercoupler, between the "ground" and the person "grounded" eliminates the possibility of shock to those in the intercoupled group but does not prevent short-circuit sparking. The surgeon or a nurse, who are usually not included in the intercoupled group, may still be badly shocked or killed if he or she is standing in leather-soled shoes (which are conductive) on a "grounded" floor.

To prevent short-circuit sparking or electrical shock, it is necessary to check regularly the insulation of the diathermy equipment (in fact, all electrical apparatus on a house current) by means known to every electrician with the aid of a megger. It requires vigilance, circumspection, and repeated inspection to employ safely the modern equipment of surgery. These virtues are rarely used in most operating rooms until after the first accident has been experienced.

CLINICAL DATA

We have recorded 20 cases of fires and explosions ignited by diathermy apparatus. Three cases involving ether-air caused no injury; 8 cases of ether mixed with high concentrations of a source of oxygen (nitrous oxide or/and oxygen) resulted in the death of 2 patients, the serious injury of a third patient and 3 bystanders, and the slight injury of a patient and 2 bystanders. One case of nitrous oxide-oxygen containing an unknown combustible seriously injured the patient. Two cases of ethylene-oxygen caused the death of 1 patient and in another the rupture of the urinary bladder with recovery following repair. Two cases of cyclopropane-oxygen occurred, with the death of 1 patient. There were 3 cases of surgical field fires: alcohol ignited in 2 with the death of 1 patient, and ether ignited in 1 instance with death of the patient.

The igniting spark appeared at the active electrode, where the threat is exactly identical with that presented by the actual cautery tip, in 14 cases. The detailed consideration of this type of obvious hazard would be only a repetition of our discussion of the cautery hazard, to which the reader is referred.

In the remaining cases, the igniting spark occurred in unexpected and unpredictable places in or near the respiratory path of the combustible anesthetics although both the inactive and active electrodes were deliberately and probably effectively kept out of contact with the gases. In these cases (definitely in 4 cases, and probably in 2 cases) the spark was of the type which is less obvious and more difficult of prevention, namely, the "diffuse sparking" which has been described in paragraph 5 of the electrical data presented in the early part of this paper.

SUMMARY AND CONCLUSION

We have considered in detail the electrical basis of all sparking or arcing during the use of high frequency apparatus. The prevention of all sparks is impossible. The localization of the hazard to one restricted zone, as is possible with the actual cautery, is practically impossible. No matter how far from the mask the electrodes are placed, there is serious danger of spark ignition of a combustible inhalation anesthetic mixture. In view of the relatively narrow field of use of surgical diathermy and because of the practical impossibility of spark prevention during diathermy, we have reached the conclusion that combustible anesthesia is contraindicated by the surgical need for diathermy in any part of the head, neck, body, and extremities.

We have directed attention to the other hazards of surgical diathermy in the operating room, namely, surgical field fires, fulguration-produced explosions of hydrogen in the urinary bladder and electric shock and sparking resulting from short-circuits in defective apparatus.

Our study forces us to conclude with the bald statement:

Anesthetic fires and explosions ignited by diathermy, like those due to x-ray apparatus, are completely preventable only by the use of noncombustible anesthetic methods. Failure to use such methods in the presence of diathermy is an admission of inability to maintain the standards of safe anesthesia which have long been advocated by many authorities, which are here demonstrated as necessary, and which are now practiced in the better departments of anesthesia and surgery.

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